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Nordic Seas dissolved oxygen data in CARINA

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Abstract

Water column data of carbon and carbon relevant hydrographic and hydrochemical parameters from 188 previously non-publicly available cruises in the Arctic, Atlantic, and Southern Ocean have been retrieved and merged into a new database: CARINA (CARbon IN the Atlantic). The data have been subject to rigorous quality control (QC) in order to ensure highest possible quality and consistency. The data for most of the parameters included were examined in order to quantify systematic biases in the reported values, i.e. secondary quality control. Significant biases have been corrected for in the data products, i.e. the three merged files with measured, calculated, and interpolated values for each of the three CARINA regions; the Arctic Mediterranean Seas (AMS), the Atlantic (ATL), and the Southern Ocean (SO). With the adjustments the CARINA database is consistent both internally as well as with GLODAP (Key et al., 2004) and is suitable for accurate assessments of, for example, oceanic carbon inventories and uptake rates and for model validation. The Arctic Mediterranean Seas includes the Arctic Ocean and the Nordic Seas (Greenland, Norwegian, and Iceland Seas), and the quality control was carried out separately in these two areas. This contribution presents an account of the quality control of the dissolved oxygen data from the Nordic Seas in CARINA. Out of the 35 cruises from the Nordic Seas included in CARINA, 32 had oxygen data. The data from 4 of these were found to be biased low and were subject to adjustment. Thus the final CARINA data product contains oxygen data from 32 cruises from the Nordic Seas, and these data appear consistent to ±1% (corresponds to ±3 μmol kg^{-1} in the deep water).

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Data coverage and parameter measured

Repository-Reference: doi:10.3334/CDIAC/otg.CARINA.AMS.V1.2
Available at:
http://cdiac.ornl.gov/ftp/oceans/CARINA/CARINA_Database/CARINA.AMS.V1.2/
Coverage: 59.60° N–82.35° N, 35.23° W–20.01° E
Location Name: Nordic Seas
Date/Time Start: 1982-02-28
Date/Time End: 2006-02-10

Data Product Parameter Name	Data Product Flag name	Exchange File Parameter Name	Exchange File Flag Name	Units
station		STANBR		
day		DATE		
month		DATE		
year		DATE		
latitude		LATITUDE		decimal degrees
longitude		LONGITUDE		decimal degrees
cruiseno				
depth				meters
temperature		CTDTMP		°C
salinity	sf	SALNTY	SALNTY_FLAG_W	
ctdsal	ctdsf	CTDSAL	CTDSAL_FLAG_W	
pressure		CTDPRS		decibars
oxygen	of	OXYGEN	OXYGEN_FLAG_W	μmol kg^{-1}

For a complete list of all parameters available in CARINA see Key et al. (2009). Note the different names for the parameters in the Exchange files (the individual cruise files) and the merged data product.

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1 Introduction

CARINA (CARbon In the Atlantic) is a database of carbon and carbon-relevant data from hydrographic cruises in the Arctic, Atlantic and Southern Oceans. The project started as an essentially informal, unfunded project in Delmenhorst, Germany, in 1999 during the workshop on "CO_2 in the North Atlantic", with the main goal to create a uniformly formatted database of carbon relevant variables in the ocean to be used for accurate assessments of oceanic carbon inventories and uptake rates. The collection of data and the quality control (QC) of the data have been a main focus of the CARINA project. Both primary and secondary QC of the data have been performed.

The CARINA database consists of two parts: the first part is the set of the individual cruise files where all the data reported by the measurement teams are stored. Quality flags are accompanying the data, in many cases those are the flags originally reported, in others they were assigned by R. M. Key, Princeton University (Key et al., 2009). These files are in WHP (WOCE Hydrographic Program) exchange format where the first lines consist of the condensed metadata. There are essentially no calculated or interpolated values in the individual cruise files, with the exceptions of pressure calculated from depth and some bottle salinities that were taken from ctdsal. No adjustments have been applied to any of these values with the exception that all pH measurements were converted to the seawater pH scale at 25°C.

The second part of CARINA consists of three merged, quality controlled, and adjusted data files; one each for the Atlantic Ocean, Arctic Mediterranean Seas, and Southern Ocean regions. These files contain all the CARINA data and also include: 1) interpolated values for nutrients, oxygen, and salinity if those data were missing and the interpolation could be made according to certain criteria, as described in Key et al. (2009); 2) calculated carbon parameters; e.g. if total dissolved inorganic carbon (TCO_2) and total alkalinity (ALK) were measured, pH was calculated; and 3) instances where bottle salinity was missing or bad and were replaced with CTD salinity. Calculated or interpolated values have been given the quality flag "0". In many cases there

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are additional parameters in the individual cruise files, which have not been subject to secondary QC, such as $\Delta^{14}C$, $\delta^{13}C$, and SF_6. Many of these are included in the merged data files as well.

This report provides an overview of the oxygen data from the Nordic Seas data in CARINA and describes the secondary QC of these data. The data are part of the Arctic Mediterranean Seas subset of CARINA (CARINA-AMS). This subset includes data from the Nordic Seas and the Arctic Ocean. Because of the very different data coverage in these two areas, and because they are more or less separate, they were analysed separately. The oxygen data from the Arctic Ocean are described by Jütterström et al. (2009), and the other Nordic Seas data are described in Jeansson et al. (2009), Olafsson and Olsen (2009), Olsen et al. (2009), and Olsen (2009a, b). A more comprehensive description of the complete CARINA database can be found in Key et al. (2009), as well as in the other, more specialised, papers in this special issue, which includes the paper describing the oxygen data from the Atlantic Ocean region of CARINA (Stendardo et al., 2009).

2 Data Provenance and Structure

The Nordic Seas was loosely defined as the region closed by the Fram Strait to the North, Greenland to the west, the Greenland-Scotland Ridge to the South, and Norway, the Barents Sea Opening, and Spitsbergen to the east. Out of the 188 CARINA cruises, 62 are included in CARINA-AMS, and 35 of these are considered as Nordic Seas cruises. Five of these are in common with the Atlantic Ocean subset of CARINA (Tanhua et al., 2009a), in order to ensure consistency between the regions. Out of the 35 cruises included in the Nordic Seas CARINA, 32 had oxygen data and these are listed in Table 1 (see Fig. 1 for all station positions). The Nordic Seas CARINA oxygen data included in the secondary quality (QC) control span 25 years, with the earliest cruise being the 1982 Hudson (18HU19820228 (36)), and the latest the 2003 G. O. Sars cruise (58GS20030922 (128)). The more recent data are part of the Iceland

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Sea time series (184), which includes data from August 1991 through February 2006. Except for the CSS Hudson cruise in 1982 (18HU19820228 (36)), all cruises over the deeper parts of the Nordic Seas are from the period 1994 to 2003.

In the CARINA database there are two different oxygen entries: "oxygen" and "ctdoxy". "Oxygen" refers to oxygen determined in discrete samples of water drawn from water sampling bottles (e.g. Niskin bottle), using the Winkler titration method with visual or spectrophotometric end-point detection. "Ctdoxy" refers to oxygen measurements derived from the CTD oxygen sensor. It was not possible to unambiguously distinguish between the two for all cruises due to incomplete metadata, and it is almost certain that some ctdoxy values have been reported as oxygen.

3 Consistency analyses

The consistency of the Nordic Seas oxygen data was evaluated through a crossover and inversion analysis (Gouretski and Jancke, 2001; Johnson et al., 2001), carried out using the cnaX routines described by Tanhua et al. (2009b). This approach compares the deep data (>1900 m for the Nordic Seas, see Olsen et al., 2009) from two cruises that have stations in vicinity and determines the offset between the data within the crossover of the two cruises, and its standard deviation. Thus each cruise gets a set of offsets compared to the other cruises. This set of offsets are then inverted using the Weighted Least Squares (WLSQ) approach of Johnson et al. (2001) to find the corrections which maximizes the consistency of the data from the different cruises. The data from the cruises 32L919920715 (78), 32L919930718 (79) and Iceland Sea time series (184) were not included in the crossover analysis due to limited sampling depths and/or special region. These have been labelled "Not Considered" (NC) in Table 1.

The corrections determined by the WLSQ inversion of the crossover offsets are shown in Fig. 2, the crossover results in themselves can be accessed at the CARINA website (http://cdiac.ornl.gov/oceans/CARINA/Carina_inv.html). All corrections are multiplicative. Before these results are interpreted we have to make clear that there

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has been a trend of decreasing oxygen values in the deep Greenland Sea caused by an increasing fraction of Arctic deep waters in this area (Blindheim and Rey, 2004), so the results must be interpreted in light of this.

The following features are noteworthy:

1. 56JH19911105 (129) values seem very high (i.e. must be adjusted down)
2. 58JH19920712 (130) seem low compared to the other cruises from this time.
3. 58AA19940203 (116) seem a bit low compared to the other cruises from this time.
4. 58JH19940723 (135) seem a bit low compared to the other cruises from this time.
5. While it is otherwise difficult to see a clear pattern in the pre-1995 data, the data collected after 1995 clearly falls into a high and a low group.
6. 34AR19970805 (91) seems higher than any of the other high cruises from this time.

Note that the cruises have been sorted with time in Fig. 2.

4 Recommendations

Given the outcome of the crossover and inversion analyses we believe that the following cruises should be considered further: 58JH19911105 (129), 58JH19920712 (130), 58JH19940723 (135), 34AR19970805 (91), 58AA19940203 (116), 74JC19960720 (176), 58AA19961121 (120), 58AA19970225 (121), and 58AA19980308 (122)

4.1 58JH19911105 (129)

The inversion result suggested that these data are high. However, this was due to data from a single station at 3.2° E and 74.5° N, which had very high oxygen values

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of around 319–320 μmol kg^{-1}. This is 10–20 μmol kg^{-1} higher than what is normally measured in these waters. The data originator (Francisco Rey) recommended that the data is flagged 3.

4.2 58JH19920712 (130)/58JH19940723 (135)/34AR19970805 (91)

All of these cruises took place over the Greenland-Scotland ridge. This is outside the Greenland Sea where most of the other cruises took place (Fig. 3) and the number of crossovers was limited. Given this, and given that this is a highly variable region, we feel that we do not have enough evidence to recommend a specific adjustment. To signify this, these cruises have been labelled NC in Table 1.

4.3 58AA19940203 (116)

These data appear low. The cruise took place in the northern Greenland Sea (Fig. 3), and it is not inconceivable that influence of deep Arctic waters is stronger here (confirmed by salinity analyses, salinity is a bit high (Olsen et al., 2009, their Fig. 4), leading to lower oxygen values. Thus we do not recommend that these are adjusted.

4.4 74JC19960720 (176)/58AA19961121 (120)/58AA19970225 (121)/ 58AA19980308 (122)

These cruises all belong to the "high" group of the post 1995 data. By high we mean that inversion suggest that data should be adjusted down. They have – with one exception (74JC19960720 (176)) been collected by the University of Bergen (UoB). The UoB data collected after 1998 seems OK – if not a bit low (i.e. 58AA20010527 (125), 58GS20030922 (128)). The equipment used at UoB at the time was old and poor, and given this, we trust the data from IMR (all 58JH cruises), Scripps (316N cruise) and Gothenburg (77DN cruise) more than the UoB data. Our recommendation is therefore to adjust the high data.

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To determine correction factors for this group a cnaX (Tanhua et al., 2009b) analysis including only cruises covering the period of the "high" cruises was carried out. The crossover offsets were inverted using the Weighted Dampened Least Squares (WDLSQ) approach (Johnson et al., 2001), which takes into account a priori assumptions on the accuracies of the cruises involved. Specifically, the dampening factor (i.e. allowed correction) of the normal cruises was set to 1, i.e. we assume a priori that these data are OK. The dampening factor for the high cruises were set to 1.1 (i.e. a correction of up to 10% is allowed). Table 2 provides an overview of the cruises included, the dampening factors, and recommended adjustments. Corrections on the order of 0.98 and 0.99 are suggested by the inversion. We recommend that these are applied on the data.

5 Consistency test of final Nordic Seas oxygen data

In order to evaluate the consistency of the final Nordic Seas oxygen data, a cnaX crossover analysis (Tanhua et al., 2009b) was carried out after the recommendations were implemented. The corrections determined through the WLSQ inversion of the crossover offsets are shown in Fig. 2. With the exception of the three ridge cruises, 58JH19920712 (130), 58JH19940723 (135) and 34AR19970805 (91), the inversion suggest a trend of decreasing oxygen, this is consistent with the observations in the deep Greenland Sea presented by Blindheim and Rey (2004). Given this trend, these data appears consistent to within ±1%, which corresponds to $\pm 3\,\mu\text{mol kg}^{-1}$ in the deep Nordic Seas.

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References

Blindheim, J. and Rey, F.: Water-mass formation and distribution in the Nordic Seas during the 1990s, ICES J. Mar. Sci., 61, 846–863, 2004.

Gouretski, V. V. and Jancke, K.: Systematic errors as the cause for an apparent deep water property variability: global analysis of the WOCE and historical hydrographic data, Prog. Oceanogr., 48, 337–402, 2001.

Jeansson, E., Olsson, K. A., Tanhua, T., and Bullister, J. L.: Nordic Seas and Arctic Ocean CFC Data in CARINA, Earth Syst. Sci. Data Dicuss., in press, 2009.

Johnson, G. C., Robbins, P. E., and Hufford, G. E.: Systematic adjustments of hydrographic sections for internal consistency, J. Atmos. Ocean. Tech., 18, 1234–1244, 2001.

Jutterström, S., Anderson, L. G., Bates, N. R., Bellerby, R., Johannessen, T., Jones, E. P., Key, R. M., Lin, X., Olsen, A., and Omar, A. M.: Arctic Ocean data in CARINA, Earth Syst. Sci. Data Discuss., 2, 281–308, 2009, http://www.earth-syst-sci-data-discuss.net/2/281/2009/.

Kasajima, Y., Olsson, K. A., Johannessen, T., Messias, M.-J., Jeansson, E., Bellerby, R. G. J., and Skjelvan, I.: A submesoscale coherent eddy in the Greenland Sea in 2003, J. Geophys. Res., 111, C07013, doi:10.1029/2005JC003130, 2006.

Key, R. M., Kozyr, A., Sabine, C. L., Lee, K., Wanninkhof, R., Bullister, J., Feely, R. A., Millero, F., Mordy, C., and Peng, T.-H., Results from the Global Data Analysis Project (GLODAP, Global. Biogeochem. Cy., 18, GB4031, doi:10.1029/2004GB002247, 2004.

Key, R. M., Tanhua, T., Olsen, A., Hoppema, M., Jutterström, S, Schirnick, C., van Heuven, S., Kozyr, A., Lin, X., Velo., A., Wallace, D. W. R., and Mintrop, L.: The CARINA data synthesis project: introduction and overview, Earth Syst. Sci. Data Discuss., submitted, 2009.

Jeansson, E., Olsson, K. A., Tanhua, T., and Bullister, J. L.: Nordic Seas and Arctic Ocean CFC data in CARINA, Earth Syst. Sci. Data Discuss., 2, 493–536, 2009, http://www.earth-syst-sci-data-discuss.net/2/493/2009/.

Olsen, A.: Nordic Seas total dissolved inorganic carbon data in CARINA, Earth Syst. Sci. Data Discuss., 2, 181–203, 2009a, http://www.earth-syst-sci-data-discuss.net/2/181/2009/.

Olsen, A.: Nordic Seas total alkalinity data in CARINA, Earth Syst. Sci. Data Discuss., 2, 309–330, 2009b, http://www.earth-syst-sci-data-discuss.net/2/309/2009/.

Olsen, A., Key, R. M., Jeansson, E., Falck, E., Olafsson, J., van Heuven, S., Skjelvan, I., Omar, A. M., Olsson, K. A., Anderson, L. G., Jutterström, S., Rey, F., Johannessen, T., Bellerby, R. G. J., Blindheim, J., Bullister, J. L., Pfeil, B., Lin, X., Kozyr, A., Schirnick, C., Tanhua, T., and Wallace, D. W. R.: Overview of the Nordic Seas CARINA data and salinity measurements, Earth Syst. Sci. Data Discuss., 2, 1–25, 2009, http://www.earth-syst-sci-data-discuss.net/2/1/2009/.

Tanhua, T., Steinfeldt, R., Key, R. M., Brown, P., Gruber, N., Wanninkhof, R., Perez, F., Körtzinger, A., Velo, A., Schuster, U., van Heuven, S., Bullister, J. L., Stendardo, I., Hoppema, M., Olsen, A., Kozyr, A., Pierrot, D., Schirnick, C., and Wallace, D. W. R.: Atlantic Ocean CARINA data: overview and salinity adjustments, Earth Syst. Sci. Data Discuss., 2, 241–280, 2009a, http://www.earth-syst-sci-data-discuss.net/2/241/2009/.

Tanhua, T., van Heuven, S., Key, R. M., Velo, A., Olsen, A., and Schirnick, C.: Quality control procedures and methods of the CARINA database, Earth Syst. Sci. Data Discuss., 2, 205–240, 2009b, http://www.earth-syst-sci-data-discuss.net/2/205/2009/.

Stendardo, I., Gruber, N., and Körtzinger, A.: CARINA-Oxygen: a new high-quality oxygen database for the Atlantic Ocean, Earth Syst. Sci. Data Discuss., 2, 103–135, 2009, http://www.earth-syst-sci-data-discuss.net/2/103/2009/.

Table 1. Carina cruises with dissolved oxygen data in the Nordic Seas.

No[a]	EXPOCODE	Country/Institute	PI	Rec.[b]
36	18HU19820228	Canada/BIO	P. Jones	1
67	316N20020530	USA/Scripps	J. Swift	1
78	32L919920715	USA/Brookhaven	D. Wallace	NC
79	32L919930718	USA/Brookhaven	D. Wallace	NC
91	34AR19970805	Sweden/UGOT	T. Tanhua	NC
116	58AA19940203	Norway/UoB	E. Falck	1
117	58AA19940224	Norway/UoB	E. Falck	1
118	58AA19940826	Norway/UoB	E. Falck	1
119	58AA19950217	Norway/UoB	E. Falck	1
120	58AA19961121	Norway/UoB	E. Falck	0.983
121	58AA19970225	Norway/UoB	E. Falck	0.987
122	58AA19980308	Norway/UoB	E. Falck	0.991
125	58AA20010527	Norway/UoB	E. Falck	1
128	58GS20030922	Norway/IMR	F. Rey	1
129	58JH19911105	Norway/IMR	F. Rey	1
130	58JH19920712	Norway/IMR	F. Rey	NC
131	58JH19921105	Norway/IMR	F. Rey	1
133	58JH19931106	Norway/IMR	F. Rey	1
134	58JH19940525	Norway/IMR	F. Rey	1
135	58JH19940723	Norway/IMR	F. Rey	NC
136	58JH19941028	Norway/IMR	F. Rey	1
137	58JH19950427	Norway/IMR	F. Rey	1
138	58JH19951108	Norway/IMR	F. Rey	1
139	58JH19960720	Norway/IMR	F. Rey	1
140	58JH19961030	Norway/IMR	F. Rey	1
141	58JH19970414	Norway/IMR	F. Rey	1
142	58JH19980801	Norway/IMR	F. Rey	1
143	58JH19990615	Norway/IMR	F. Rey	1
144	58JH20000527	Norway/IMR	F. Rey	1
176	74JC19960720	England/UeA	A. Watson	0.982
179	77DN20020420	Sweden/UGOT	E. Falck	1
184	Iceland Sea time series	Iceland/MRI	J. Olafsson	NC

[a] Carina cruise number, is cruise identifier in merged file.
[b] Recommendations from the secondary QC. Numbers are the multiplicative adjustments.
NC = these data are probably OK, but could not be fully evaluated

Table 2. Results of the cnaX crossover and inversion (WDLSQ) analysis of the cruises falling in a high and a low group.

EXPOCODE	dampening factor	adjustment	covariance
58JH19960720	1	1	0
74JC19960720	1.1	0.982	0.027
58JH19961030	1	1	0
58AA19961121	1.1	0.983	0.016
58AA19970225	1.1	0.987	0.039
58JH19970414	1	1	0
58AA19980308	1.1	0.991	0.017
58JH19980801	1	1	0
58JH19990615	1	1	0

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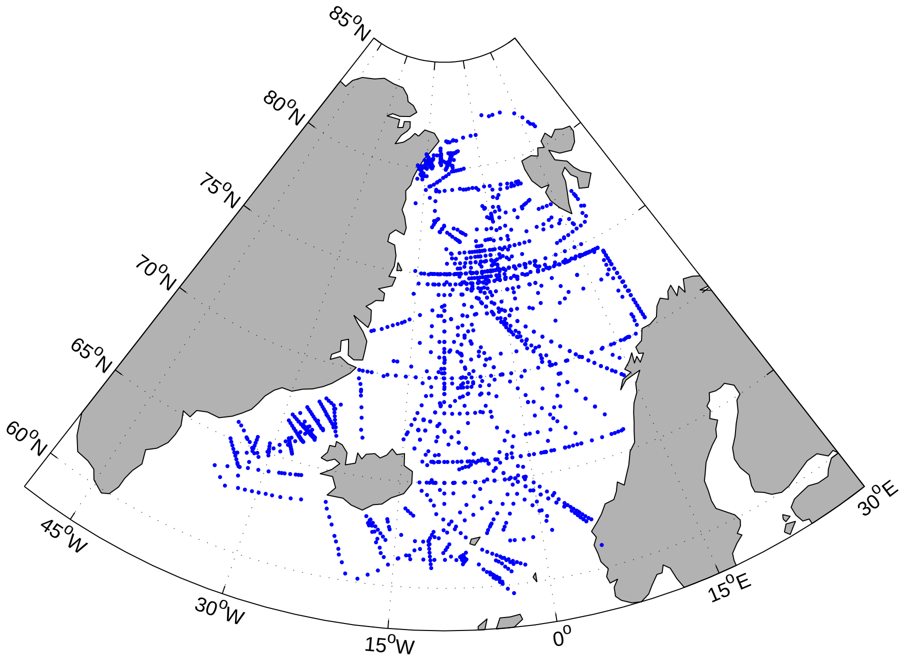

Fig. 1. The Nordic Seas with oxygen sampling positions.

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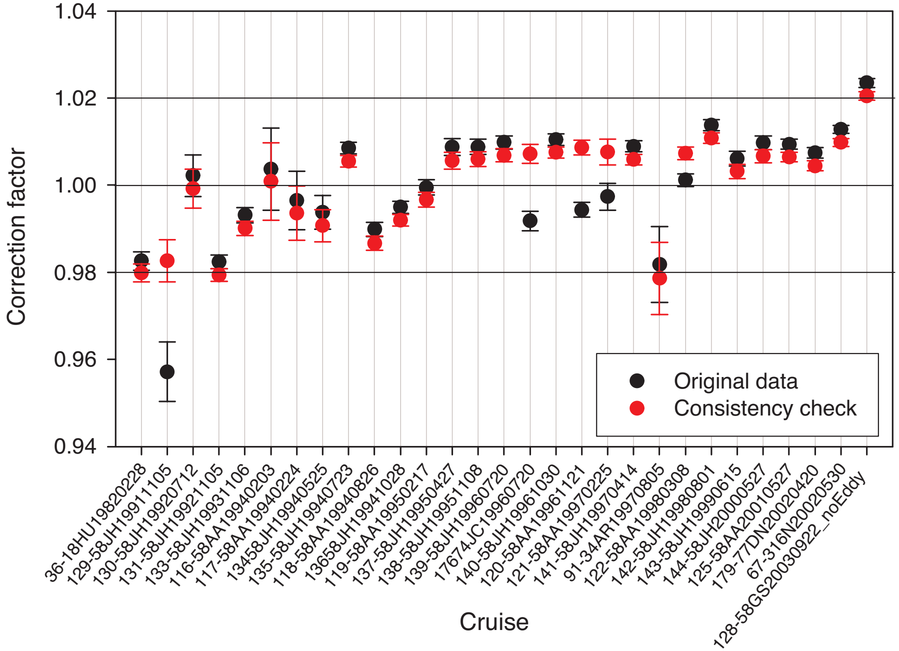

Fig. 2. Oxygen corrections (multiplicative) and their uncertainties determined through the WLSQ inversion of the crossover offsets from data with and without corrections applied. 58GS20030922 (128) had several stations in a submesoscale coherent eddy (Kasajima et al., 2006), the "_noEddy" signifies that these data were removed prior to this analysis. Note that the cruises have been sorted by time in this figure. The crossover results that were used in the inversions to prepare this figure can be accessed at the CARINA website (http://cdiac.ornl.gov/oceans/CARINA/Carina_inv.html).

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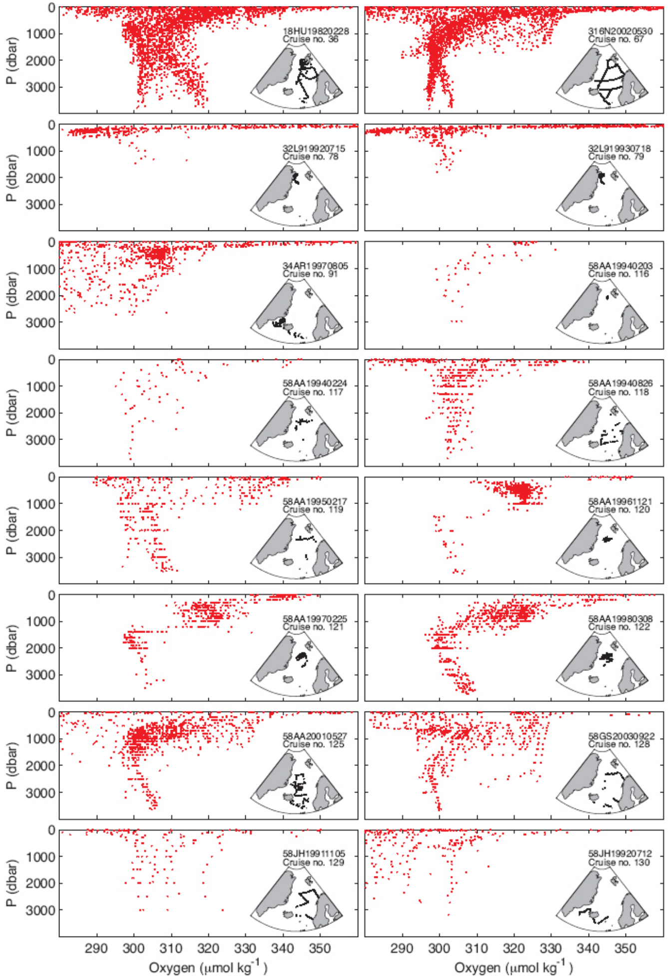

Fig. 3. Station positions and oxygen data of Nordic Seas CARINA cruises after secondary QC. All data shown in grey and specific cruise in red.

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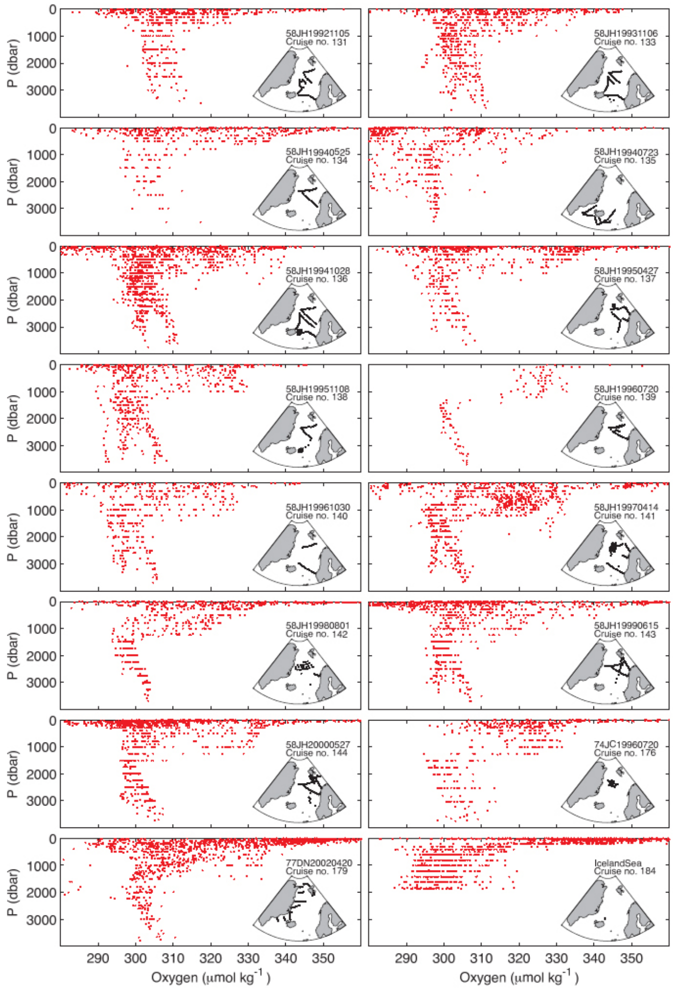

Fig. 3. Continued.

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